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THE EFFECTIVENESS OF AN INTERACTIVE MAP DISPLAY
IN TUTORING GEOGRAPHY

Allan Collins
Marilyn Jager Adams
Richard W. Pew

August 1976

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The Effectiveness of an Interactive Map Display
in Tutoring Geography

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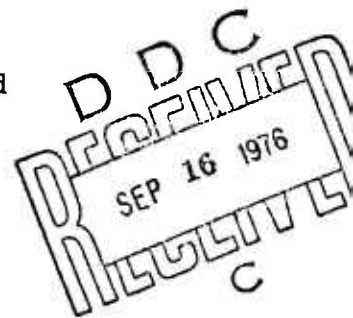
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are the unlabeled map. see pg 4

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The Effectiveness of an Interactive Map Display
in Tutoring Geography

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ABSTRACT

The purpose of this study was to evaluate the teaching effectiveness of different aspects of the SCHOLAR CAI system. The experiment compared how well students learn using SCHOLAR with (a) the interactive map display of Map-SCHOLAR (b) a static labeled map, and (c) an unlabeled map. The results of the experiment showed that the students learned significantly more with the interactive map display, than with either the labeled map or the unlabeled map. A new method called backtrace analysis was used to assess the effectiveness of specific aspects of the tutoring strategy and the map system used in the experiment.

INTRODUCTION

In developing SCHOLAR, Carbonell (Carbonell, 1970; Carbonell and Collins, 1973) took a first step toward a computer assisted instruction (CAI) system that is capable of conducting general tutorial dialogues with students. In SCHOLAR, knowledge is not stored as text, but in a precisely structured semantic network of interrelated facts and concepts (Quillian, 1968; Collins and Quillian, 1972a). Every concept used to describe a given concept can itself be described elsewhere in the network. Thus, in a nontrivial sense, the program can understand the concepts it uses. SCHOLAR also has different subroutines that use the structure of the network to formulate questions for the student, evaluate his answers, answer his questions, make inferences and computations, select new topics for discussion, etc. The attempt is to structure information like a human knowledge, so that the program can use its knowledge as flexibly as a human tutor does.

Because of its inherent flexibility, the system can be extended in a variety of ways. For example, SCHOLAR has been modified to teach different kinds of knowledge (Collins and Grignetti, 1975) and to use different teaching strategies (Collins, Warnock, and Passafiume, 1975). The educational question is which of the possible ways of varying SCHOLAR increase its teaching effectiveness. This

question is being investigated by running systematic experimental evaluations of different system configurations and different teaching strategies (Collins, 1974).

The experiment reported here was designed to test the utility of the map capability recently added to the original SCHOLAR program for teaching geography. The Map-SCHOLAR system was developed to integrate the tutoring of graphic information with verbal information. In view of the evidence that pictorial information may be remembered more easily than verbal information, (c.f. Bower, 1972; Paivio, 1971) we expected this capability to increase SCHOLAR's teaching effectiveness.

Map-SCHOLAR can discuss with the student different maps that change dynamically according to the context of the discussion. To do this, a graphic structure was created which parallels the structure in the semantic network. The elements in the map display can be referred to either by their name, or by pointing to them, or both. Map-SCHOLAR both asks and answers map-related questions and provides relevant map information when the student makes a mistake. In short, Map-SCHOLAR has all the capabilities of the original SCHOLAR with the addition of the map capabilities.

Figure 1 illustrates some of the variety of interactions possible with Map-SCHOLAR. The first panel illustrates how Map-SCHOLAR asks map-related questions,

NOW LET'S SEE WHAT YOU REMEMBER ABOUT THE CITIES OF BRAZIL.
PLEASE NAME THE PRINCIPAL CITIES OF BRAZIL NOW BLINKING
ON THE DISPLAY SCREEN.

MANAOS SAO PAULO AND LIMA

MANAOS AND SAO PAULO ARE CORRECT. LIMA IS IN PERU, NOT IN BRAZIL.
THE PRINCIPAL CITIES OF BRAZIL ARE BLINKING ON THE SCREEN.

RIO DE JANEIRO IS IN SOUTHEASTERN BRAZIL.
IT IS ON GUANABARA BAY AND THE ATLANTIC.

BRASILIA IS IN CENTRAL BRAZIL.
IT IS FAR FROM THE OCEAN.



Fig. 1 Interactions with Map-SCHOLAR

PLEASE POINT TO THE FOLLOWING CITIES OF THE AMAZON
IN THE ORDER IN WHICH THEY APPEAR BELOW:
MANAOS, BELEM, AND IQUITOS
DON'T FORGET TO LET ME KNOW WHEN YOU ARE FINISHED,
PLEASE REMEMBER TO TYPE AN ASTERISK * FOLLOWED BY A
CARRIAGE RETURN.

**

MANAOS IS CORRECT. YOU DID NOT POINT AT BELEM AND IQUITOS CORRECTLY.
THE CITIES OF THE AMAZON ARE BLINKING ON THE SCREEN.



Fig. 1 Interactions with Map-SCHOLAR (cont)

LET'S BEGIN BY TALKING ABOUT THE TOPOGRAPHY OF VENEZUELA.
THE PRINCIPAL LAKE OF VENEZUELA IS BLINKING, PLEASE NAME IT.

I DON'T KNOW

THE PRINCIPAL LAKE OF VENEZUELA IS BLINKING ON THE SCREEN.

LAKE MARACAIBO IS IN NORTHWESTERN VENEZUELA.
THE PRINCIPAL MINERAL IS OIL.

IS THIS COUNTRY COLOMBIA?

YES, THAT'S COLOMBIA

WHERE IS THE CAPITAL OF VENEZUELA?

CARACAS IS BLINKING.



Fig. 1 Interactions with Map-SCHOLAR (cont)

evaluates the student's answers, and corrects his mistakes. First, the dots indicating the location of the cities appear unlabeled on the map of Brazil and start blinking. Then SCHOLAR asks the student to name the blinking cities. When he responds, it tells him which answers were correct and prints their names on the map. Because he erroneously gave Lima as an answer, Map-SCHOLAR pointed out that Lima is in Peru and showed where Lima is on the map. Thus, Map-Scholar gives both verbal and visual feedback to help the student learn the material.

The second panel shows how context affects the map display. The topic is the Amazon, which appears in this context on the map of Brazil, the overall topic. The question asks the student to point at the cities along the Amazon in the order named. The dots for the three cities first appear unlabeled, and only after the student has answered do the labels appear. Unlike the first map, this map shows only the cities on the Amazon and their relation to the Amazon. There is also expansion of detail so that a city like Belem, which was not important enough to be included among the cities of Brazil, is included with the subtopic of the Amazon. Because the map changes dynamically as the context changes and as the student interacts with the system, the student's attention is focused on the relevant information, and questions can be posed in a visual form not possible with a static map display.

The third panel shows the system's potential for tutorial interaction. When the student didn't know about Lake Maracaibo, Map-SCHOLAR showed it on the screen and added the related verbal information about the oil there. This example also illustrates some of the ways in which the student can ask Map-SCHOLAR to clarify or amplify the information given (Collins and Warnock, 1974). For the first question the student both pointed at and named Colombia to ask if it is the country near Lake Maracaibo. For the second question, the student verbally asked where the capital of Venezuela is, perhaps to find out how far away it is. SCHOLAR figured out semantically that the capital is Caracas, and then visually showed where Caracas is by blinking it (it is the double square). These examples illustrate some of the power for tutorial interaction that can be obtained by a close integration between semantic and visual knowledge.

In order to test the utility of the map system for teaching, we conducted an experiment in which each student learned about a different country under one of three conditions: one condition used SCHOLAR on the map system; the second condition used SCHOLAR on a non-graphic terminal, but the student could look at a labeled map of the country; the third condition was like the second, except that the student was given an unlabeled map. Students' learning for each of the three kinds of training sessions was measured by

comparing their scores on a pre-test to those on a post-test given three days after the last training session.

A second goal of this experiment was to investigate how specific aspects of the tutorial dialogue affect students' learning. To study this question, we developed a technique called backtrace analysis. The technique involves marking each piece of information that is discussed according to the kind of exchange involved (e.g., a question requiring a pointing response vs. a naming response). By comparing this data to the student's answers on the post-test, it is possible to identify the kinds of tutorial interactions that most strongly influence the student's learning.

METHOD

Subjects. The initial group of subjects included nine high school students. The study was replicated with nine university students. All subjects were volunteers and were paid for their services.

Design. There were three experimental conditions: a Map-SCHOLAR condition, a Labeled Map condition, and an Unlabeled Map condition. The Map-SCHOLAR condition was run on an Imlac graphic terminal with the screen divided between maps and verbal communications as shown in Figure 1. The student could input questions and answers by a keyboard and an electronic pointer (a "mouse"). The Labeled and

Unlabeled Map conditions were run on a keyboard terminal using a non-graphic version of SCHOLAR called Tutor-SCHOLAR (Collins, Warnock, and Passafiume, 1975). The two versions of SCHOLAR were identical with respect to both teaching strategy and information in the data base, except that Map-SCHOLAR handled all location-related questions in terms of the map, whereas Tutor-SCHOLAR handled them verbally. In the Labeled Map condition, subjects were given a paper map which marked all the places (names and locations) included in the Map-SCHOLAR data base. In the Unlabeled Map condition, subjects were given copies of the same maps, omitting the names of the places that were marked on the maps. For both of these conditions, students were instructed not to mark on the maps. The pre-test, post-test, and the final questionnaire were given in paper and pencil format.

Procedure. Each student participated in a preliminary session, three tutorial sessions, and a post-test session. The first purpose of the preliminary session was to administer the pre-test. The pre-test measured the student's pre-experimental knowledge about the information to be tutored, and consisted of 20 basic questions about the geography of each of the three relevant countries: Argentina, Brazil, and Venezuela. A secondary purpose of the pre-test was to ascertain that no subject was inordinately familiar or unfamiliar with any one of these

three countries, since such inequalities in prior knowledge would confound measures of teaching effectiveness. After having completed the pre-test, the student was given a brief, introductory lesson on a fourth country, Chile, using Map-SCHOLAR. The purpose of this lesson was to familiarize the student with the system and its capabilities or, more specifically, with the kinds of questions he would be asked, the kinds of answers that were expected of him, the kinds of questions he could ask of SCHOLAR, the use of the keyboard and the pointer, and the methods by which he could correct his input errors.

The tutorial phase of the experiment consisted in three, two hour sessions, administered on consecutive days. During these sessions, each student learned about one country in the Map-SCHOLAR condition, one in the Labeled Map condition, and one in the Unlabeled Map condition. Each lesson lasted for one hour. After the student had received one lesson on each of the three countries, the series was repeated. The combinations of countries and teaching modes were counterbalanced and ordered according to a 3×3 , confounded, factorial design (Winer, 1971, p. 646).

The final session was conducted three days after the last tutorial session. In this session, the student took the post-test and completed a questionnaire on those aspects of the lessons that he had found most and least helpful.

The post-test was divided into three parts. The first part consisted of 36 basic questions (including the 20 that had been on the pre-test) about each of the three countries. For the second part of the post-test, the student was given a map of each of the three countries and asked to label the geographical features indicated. The third part of the post-test consisted of 32 more difficult questions about each of the countries.

Backtrace Analysis. In order to assess the value of specific aspects of the tutorial exchange, we developed the technique of backtrace analysis. This technique involves marking each entry in SCHOLAR's database with respect to the way in which it is treated during a given tutorial session. This information can subsequently be retrieved, enabling us to evaluate the effectiveness of SCHOLAR's various interactive capabilities from the probabilities with which they result in correct answers on the post-test.

More specifically, each item that was discussed in a given session was tagged with information concerning (1) the temporal order, (2) the context, and (3) the training event in which it arose. For purposes of the backtrace analysis, the training events were classified as follows:

- a) True-False Correct - SCHOLAR presents a true-false question which the student answers correctly. SCHOLAR tells the student he is correct and moves on to new

information.

- b) True-False Error - SCHOLAR presents a true-false question and the student answers incorrectly or pleads ignorance. SCHOLAR points out the correct answer and goes on.
- c) Name Correct - The student correctly names a geographical feature(s) in response to SCHOLAR's request. Each answer among a set of answers is tagged individually. This category subsumes what and where questions as well as fill-in-the-blanks and naming requests by SCHOLAR.
- d) Name Error - The student incorrectly names or fails to name a geographical feature when questioned by SCHOLAR.
- e) SCHOLAR Error Correction - If the student completes a fill-in question erroneously, SCHOLAR infers the basis of the student's error and then presents new information to distinguish between the student's answer and the correct answer.
- f) SCHOLAR elaboration - If the student misses a question, SCHOLAR presents related information at the same level of importance (See Fig. 1). The related material is tagged as an elaboration.
- g) Student Question - Information is introduced as the result of a question the student asks of SCHOLAR.

In addition to the above, there were several categories of training events which occurred only in Map-SCHOLAR. SCHOLAR treated these events like fill-ins, but they were

distinctively marked for purposes of the backtrace analysis:

- h) Label - SCHOLAR asks the student to name those features of the map that are blinking.
- i) Point - SCHOLAR asks the student to point to the specified geographical features on the map.
- j) Label and Point - SCHOLAR asks the student to name and point to a specified set of geographical features.

RESULTS AND DISCUSSION

The pre-test scores were examined using a 3 X 2 (Countries X Groups) repeated measures analysis of variance (Winer, 1971, p. 518). The only significant effect was due to groups, as the college students generally scored higher than the high school students. The number of correctly answered questions, out of the possible 20 per pre-test, ranged from 1 to 11 (median = 4.67) for the college students and from 0 to 5 (median = 0.64) for the high school students. Neither the main effect of countries ($F(2,32) = 2.62, p > 0.05$) nor the interaction between countries and groups ($F(2,32) = 1.36, p > 0.05$) approached significance. Inasmuch as none of the subjects knew much about any of the countries in advance, the difference between pre- and post-test scores should provide a fair estimate of SCHOLAR's teaching effectiveness. Moreover, since the subjects' prior knowledge seemed to be evenly distributed

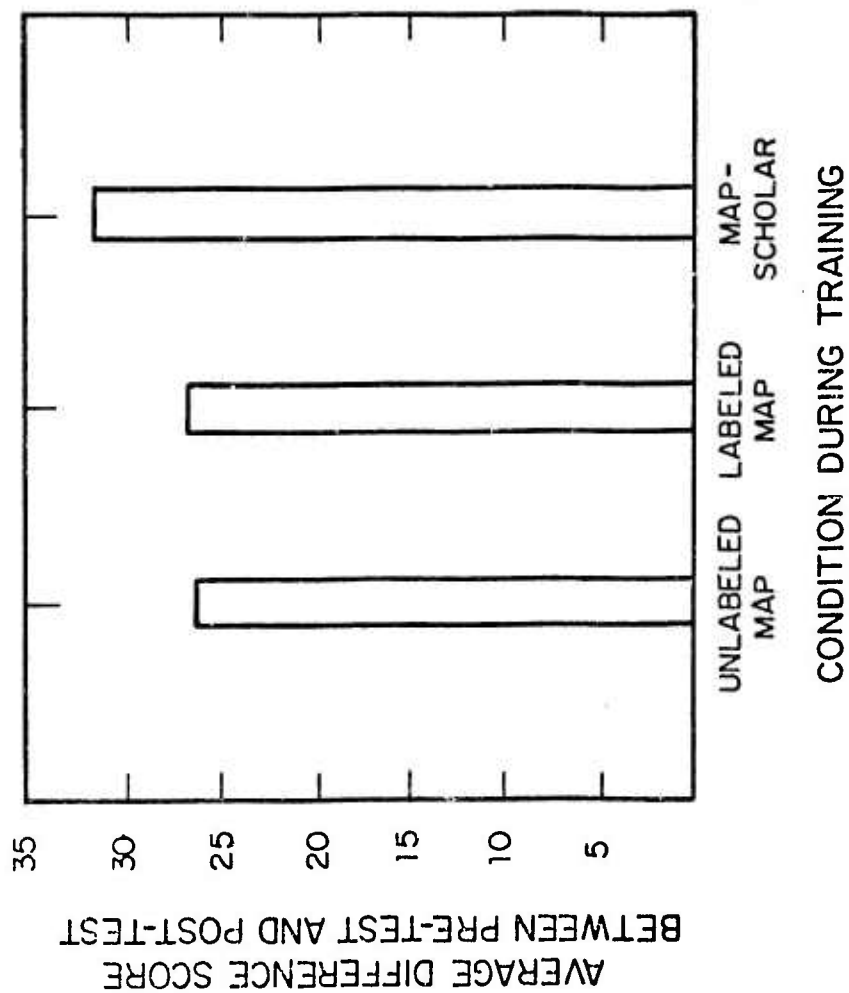
across countries, the relative teaching effectiveness of the three conditions could be estimated through direct comparisons of the corresponding pre-test/post-test difference scores.

The average increase in the number of correct responses from the pre-test to the post-test is shown in Figure 2 for each teaching mode. These difference scores were analyzed according to a 3 X 3 (teaching modes X countries) confounded factorial design. Whereas neither the effect of countries ($F(2,28) < 1.0$) nor the interaction between countries and teaching conditions ($F(4,28) = 2.08$, $p > 0.05$) was significant, the effect of training condition was strongly significant ($F(2,28) = 6.05$, $p < 0.01$). According to a Newman-Keuls test ($p < 0.01$), the Map-SCHOLAR condition resulted in significantly higher post-test scores than the Labeled Map condition which, in turn, resulted in significantly higher scores than the Unlabeled Map condition.

Separate analyses of the three parts of the post-test indicated that much of the effect of teaching modes occurred in the part of the test consisting of map labeling questions ($F(2,28) = 14.09$, $p < 0.001$). However, a pronounced effect of teaching mode was also obtained for the easier, non-map questions in the first part of the post-test ($F(2,28) = 5.85$, $p < 0.01$). Although the

FIGURE 2

AMOUNT LEARNED AS A FUNCTION
OF THE CONDITION DURING TRAINING



scores on the more difficult questions in the third part of the post-test were too noisy to yield any significant effects or interactions under analysis, the same trend was apparent. In short, post-test scores were consistently highest in the Map-SCHOLAR condition and lowest in the Unlabeled Map condition.

These results indicate that the map system not only helped students learn the information necessary to answer the map questions in Part 2 of the post-test, but also to answer the verbal questions in Parts 1 and 3 of the post-test. An important question is whether the benefit of the map system extended only to verbal information that was explicitly about locations, or whether it also extended to non-location information, such as the climate or terrain of a place. Clearly, one would expect the map system to help students learn location information better, but there are two reasons why the map system might help students learn non-location information better as well. First, if map information showing where a place like Manaus is located helps the student remember Manaus better, then non-map facts about Manaus, such as its climate, may be remembered better. This is because the best way to learn something is to relate it to information already known (Collins and Quillian, 1972b; Norman, 1973). Second, if a student sees that Manaus is on the Amazon, then Manaus' climate can be related to any

prior knowledge about the climate of the Amazon (e.g. that the Amazon flows through jungle). Thus, even non-map information may be better remembered in a visual context.

This idea was tested with backtrace analysis by separating the questions during training into map questions and non-map questions, depending on whether the questions were posed visually by the map system. Then the percentage correct on the post-test for the two types of presentation during training were plotted (see Figure 3). For map questions, as expected, students learned significantly more with Map-SCHOLAR than with either the labeled or unlabeled maps. But for non-map information there were no significant differences, and students even did slightly better in the Unlabeled Map condition. Thus, these data suggest that the major benefit of the map system is in learning information about specific locations.

Backtrace analysis was also used to investigate the effectiveness of repeating questions, depending on whether the student answers correctly or incorrectly. Figure 4 shows the percentage of correct responses to each item on the post-test as a function of how frequently the students were correct or wrong on that item during training. The increases in the curves show

FIGURE 3

POST-TEST PERFORMANCE ON
MAP & NON-MAP QUESTIONS FOR EACH CONDITION

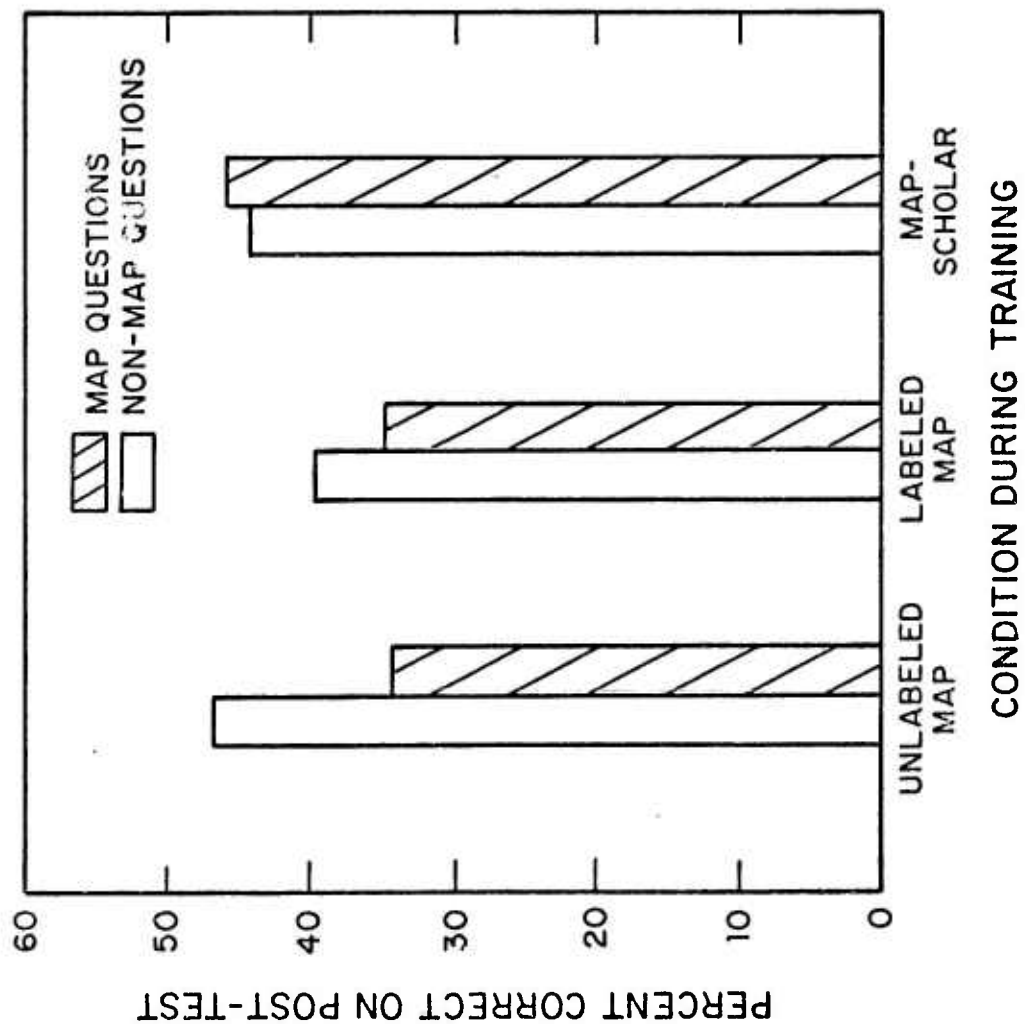
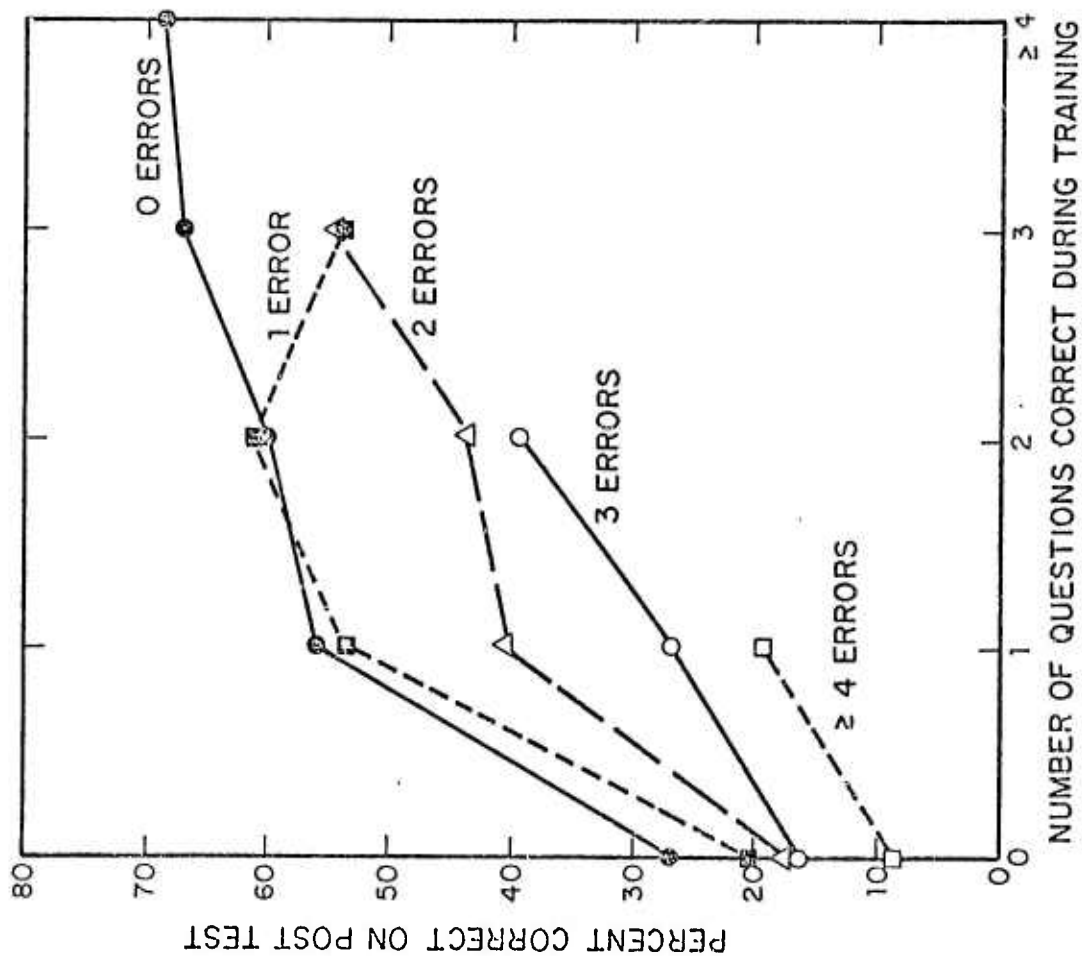


FIGURE 4

PERCENT CORRECT ON THE POST TEST AS A FUNCTION OF
NUMBER CORRECT OR IN ERROR DURING TRAINING



that the more frequently a student answered any item correctly, the more likely he was to recall it on the post-test. The separation of the curves for different numbers of errors shows that the more frequently an item was missed, the less likely it was to be recalled on the post-test. This simply reflects the fact that the items that were more difficult to learn were likely to be missed more frequently. The concave shape of the curves indicates that the repeated presentation of a correct item has a decreasing effectiveness. The implication is that, as far as possible, training time should be allocated to those items that the student has correctly answered least often.

When students missed items in answering a question, SCHOLAR provided additional elaboration about some of the items missed. For example, in Figure 1 when the student did not know Lake Maracaibo, SCHOLAR mentioned the oil there as an elaboration about Lake Maracaibo. The backtrace analysis showed that percent correct on the post-test increased from 34% when there was no elaboration of an item during training to 47% when there was one elaboration. This increase is significant ($t = 4.01, p < 0.01$), indicating that elaboration does help students to learn the material better. After one elaboration, the percent correct stabilizes, indicating that further elaborations are of little benefit.

We used a variation of backtrace analysis to determine which kinds of map questions are most effective for learning. In the map system there were three different kinds of map questions that might be asked: (1) pointing questions, where SCHOLAR mentioned one or more places and asked the student to point at them (2) naming questions, where SCHOLAR blinked one or more places and asked the student to name them, and (3) pointing and naming questions, where SCHOLAR asked the student to name a set of places, such as the rivers in Brazil, and point to them in the order named.

Figure 5 shows the percent correct on the second occurrence of a map question about any item as a function of the type of question that was asked on the first occurrence of that item. There were not enough data for naming questions, so they are not shown. The column totals indicate that students did better on pointing questions than on pointing and naming questions, as would be expected because pointing questions are easier. However, the row totals show that students did better on the second question if the first question had required both pointing and naming than if it had required only pointing ($\chi^2(1) = 4.75, p < 0.05$). Evidently, students learn more from pointing to and naming a location than from just pointing to it.

FIGURE 5

THE EFFECT OF DIFFERENT TYPES OF MAP QUESTIONS DURING TRAINING

| TYPE OF QUESTION ON FIRST OCCURRENCE | PERCENT CORRECT ON SECOND OCCURRENCE | | P<0.05 |
|---|---|---------------------------|--------|
| | POINTING | NAMING AND POINTING | |
| POINTING | 49% | 33% | 40% |
| NAMING AND POINTING | 61% | 51% | 54% |
| | 53% | 41% | |
| | P<0.10 | | |

CONCLUSION

The experiment showed that students learned significantly more with the interactive map display than with either a static labeled or unlabeled map. The advantage of Map-SCHOLAR cannot be attributed solely to the ability of the student to locate places spatially, since the Labeled Map condition allowed the student to identify places just as effectively. The advantage of Map-SCHOLAR also cannot be attributed to novelty or some other generalized facilitation effect, because, as backtrace analysis showed, the effect was specific to location information and did not carry over to non-location information. The advantage therefore must have been due mainly to the dynamic aspects of Map-SCHOLAR and its ability to focus the student's attention on the relevant map information.

The experiment also demonstrated the usefulness of the backtrace analysis technique for evaluating CAI systems. Backtrace analysis is not dependent on the type of information being taught, and is thus transferable to CAI systems other than SCHOLAR. Of course, the specific tags used to mark the data would change, depending on the different teaching strategies and training events that are being evaluated. The ability to perform fine-grain analyses of the effectiveness of different teaching

strategies is a valuable tool for future educational research.

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